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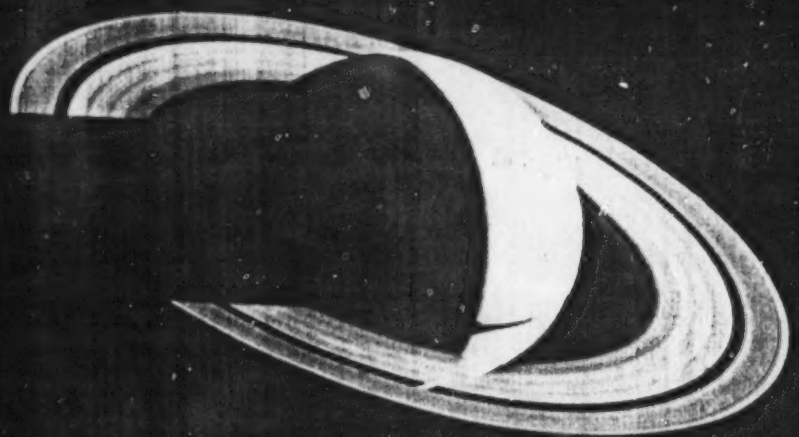
# Voyager at Saturn: 1981



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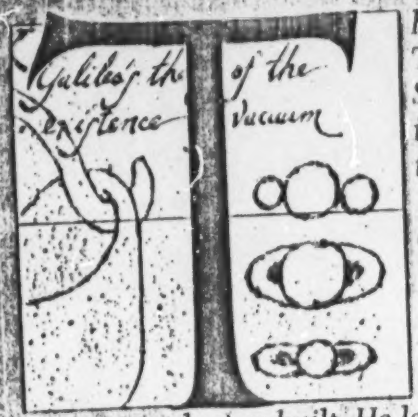


The year is 1610. Shakespeare's plays are the glory of England. The first newspapers have just been published in Europe. The Spanish are exploring the New World and feverishly harvesting its riches. Scholars are compiling the King James version of the Bible that will be published next year.

It is 67 years since a rebel Polish priest named Nicolaus Copernicus published his heretical description of the universe—a description that is shunned by the Church, even in this enlightened year of 1610.

On cold, clear winter evenings this year, an Italian scientist named Galileo Galilei is peering at the heavens with a new instrument he has built. He learned about this device, which he calls a telescope, from a Dutch spectacle maker. Among the celestial objects Galileo studies is Saturn, the most distant planet he knows about. Galileo turns his tiny, crude telescope toward Saturn. He is ill-prepared for the surprise the instrument provides.

Galileo has found other surprises in his surveys of the heavens, but Saturn appears, unbelievably, to have knobs protruding from its sides!

Or are they knobs? Could they be—his telescope is primitive and small—"cup handles?" His next conclusion: Two or more satellites must lie so close to Saturn that his telescope can't separate them. Later he decides even that conclusion is wrong.

Time passes and more pressing things—including his own trial by the Inquisition on charges of heresy—occupy Galileo's time and thoughts. Because he is the most respected scientist of his time, and by recanting the heresy that the Sun is the center of the universe, Galileo survives the trial.

Years later, old and isolated from the world, Galileo again turns his telescope to Saturn. As he looks, his hands tremble, he shakes his head in disbelief, blinks his eyes, and stares again. The "cup handles," or whatever they were, have disappeared!

"God has tricked me," the deeply religious scientist writes this night in his journal.

Today we know that Galileo wasn't tricked, but that every 15 years Saturn's rings—the "cup handles"—turn edge-on to Earth and disappear from our view.

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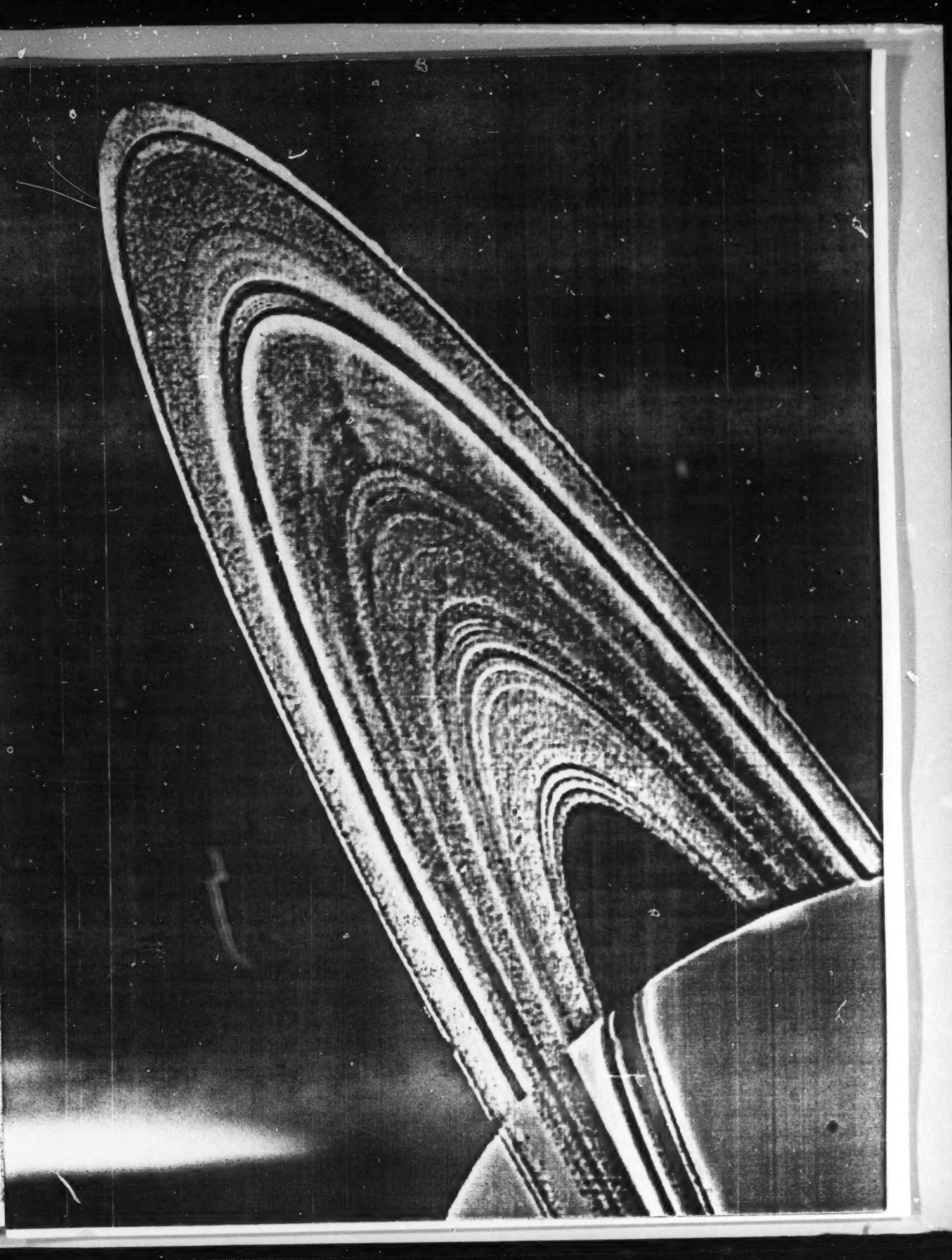
*Facing page: Could Galileo have imagined that a spacecraft would one day travel to Saturn and beyond? This false-color photograph was taken on October 30, 1980, when Voyager 1 was 18 million kilometers from Saturn. Each of the three photographs used for this composite was taken through a different filter at a different time, causing the rainbow effect in the rings.*

*Cover: As Voyager 1 soared upward and outward from the Saturnian system, the spacecraft photographed Saturn on November 16, 1980, from 5.3 million kilometers away.*



## The Mission to Saturn

Voyager 2 will fly past Saturn on August 25, 1981, following on the heels of Voyager 1's successful November 1980 encounter. Voyagers 1 and 2 were launched from Cape Canaveral, Florida, toward the outer planets in late summer 1977. Voyager 1 flew past Jupiter in March 1979, and Voyager 2 followed four months later.

Each Voyager carries 11 instruments to examine Saturn, its rings, and its satellites. The experiments were chosen to produce a broad understanding of the Saturnian system.

Voyager 2's Saturn encounter began on June 5, 1981, at a distance of 77 million kilometers from Saturn. The instruments began a four-month-long scrutiny of the Saturnian system.

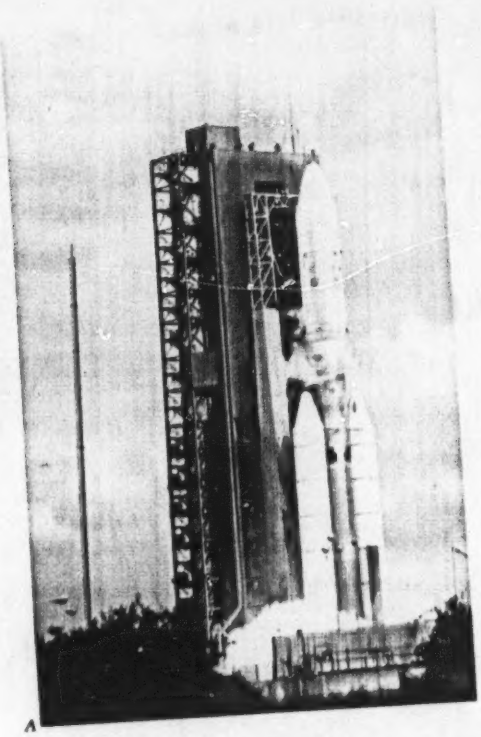
Among the earliest observations of Saturn was a series of photographs, taken every two hours for 60 days. The series began in early June, when the spacecraft was close enough to take better pictures than the best from Earth. Meanwhile, other instruments were also making observations on a regular basis.

Ultraviolet and infrared instruments have been scanning the region, measuring the composition and temperature of Saturn's cloudtops and the satellites' surfaces. Magnetometers and charged-particle detectors have been analyzing Saturn's magnetic field and how it reacts with the solar wind. A radio-astronomy receiver has been listening to the sounds of space and Saturn, while a plasma-wave detector has been measuring variations in the plasma.

By July 31, when Voyager 2 was 24.7 million kilometers from Saturn, the narrow-angle camera could no longer capture all of Saturn's disk in a single picture. Then the camera began photographing small segments of the disk; the pictures fit together in mosaics to reveal details in the banded clouds.

By August 10, even four-photograph mosaics of Saturn did not capture the entire disk. Both the wide-angle and narrow-angle cameras were directed, instead, to concentrate on atmospheric phenomena that deserve special attention. Mosaics and single photographs covered progressively smaller sections of the planet. The infrared instrument began to map the temperatures of Saturn and the satellites.

Shortly before closest approach to the planet, Voyager's photopolarimeter will spend two hours studying the rings as they pass before a star called Delta Scorpii, to learn more about the hundreds of unexpected ringlets discovered by Voyager 1.



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B

As it speeds toward Saturn, Voyager 2 will make distant observations of Titan. Finally, the spacecraft will fly past the planet at 8:25 P.M. (PDT) on August 25, only 101,000 kilometers above the cloudtops and, a few minutes later, will skim within 36,000 kilometers of the A-ring.

Voyager's radio will become a science instrument when the spacecraft flies behind Saturn and its rings on August 25. The radio signals change as they pass through Saturn's atmosphere and rings on their way to Earth. Those changes provide data on gases and pressures in the atmosphere and particles in the rings.

Peering backward as it streaks away, Voyager 2 will continue to monitor the Saturnian system until the evening of September 28. The spacecraft will be on its way to Uranus, arriving there in January 1986.

## *Saturn*

Saturn is one of the solar system's four giants; the others are Jupiter, Uranus, and Neptune. While all are similar on a gross scale—huge accumulations of hydrogen and helium with small, rocky cores—each exhibits its own significant and unique properties. In Earth-based telescopes, Saturn appears to be a smaller version of Jupiter, but Voyager 1 improved our perspective.

Since Saturn is so far from the Sun—twice as far as Jupiter—it is much colder. Material such as ammonia freezes at greater depths in Saturn's atmosphere than on Jupiter. Saturn also displays fewer and more subtle atmospheric phenomena than Jupiter. Saturn's more subdued appearance may be due to a thick layer of haze above the clouds, hiding them even from the eyes of Voyager.

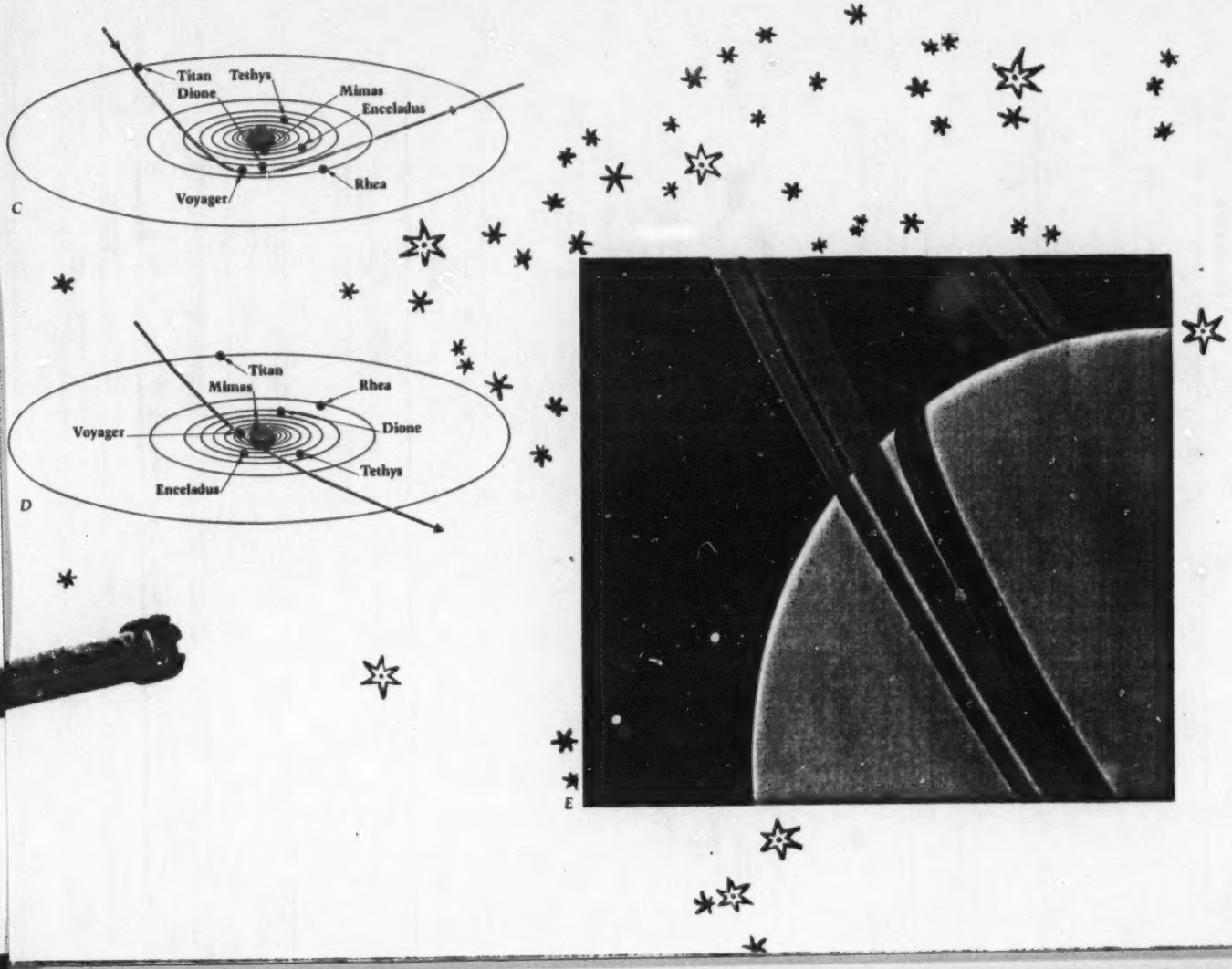
*A. Two Voyager spacecraft were launched from Cape Canaveral, Florida, in the summer of 1977, beginning their journey to Jupiter, Saturn, and beyond.*

*B. Voyagers 1 and 2 flew past Jupiter in 1979. This picture of Jupiter, Io (left), and Europa (right) was taken by Voyager 1 in February 1979 from 20 million kilometers.*

*C.* ***November 12, 1980*** *Voyager 1's closest approach to Saturn was 125,000 kilometers from the cloudtops. Six of the satellites that were photographed are shown in their approximate positions at closest approach by the spacecraft.*

*D.* ***August 25, 1981*** *Voyager 2 will fly closer to Saturn than Voyager 1, passing about 101,000 kilometers from the cloudtops. Again, the satellites are shown in their closest approach positions.*

*E. Saturn, its rings, and two of its moons, Tethys (above) and Dione (below), were photographed by Voyager 1 on November 3, 1980, from 13 million kilometers.*



The winds on Saturn blow substantially faster than on Jupiter. The highest Saturnian winds measured by Voyager 1 were about 1,800 kilometers an hour, a wind speed more than four times faster than the highest Jovian winds. Voyager scientists have not yet found a satisfactory explanation for this surprising discovery.

Voyager 1 provided the first clear, close-up views of Saturn. Voyager 2 will follow up on the discoveries of Voyager 1; scientists and engineers have restructured the mission profile of the second encounter to take advantage of what was learned during the first encounter.

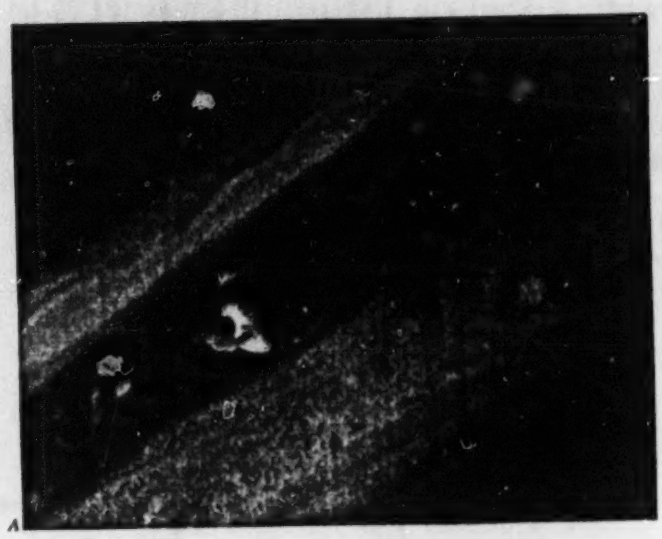
Scientists only recently confirmed that Saturn has a magnetic field. NASA's Pioneer 11 made the first measurements of the field in 1979, and Voyager 1 determined the rate of rotation of the magnetic field.

Saturn was thought to have about 11 satellites—almost as many as Jupiter. But data from Voyager 1 and telescopic observations from Earth when Saturn's rings turned edge-on late in 1979 (as they did for Galileo long ago) show Saturn has at least 17.

One key difference between Jupiter and Saturn that is of special interest to Voyager scientists is the planetary mechanism for generating internal heat. Jupiter radiates about 1.8 times as much energy as it receives from the Sun. That heat, theoreticians believe, was generated 4.6 billion years ago by gravitational collapse of the planet. Jupiter is so large that its primordial heat has been escaping ever since. Saturn, however, emits about 2.5 times the energy it receives from the Sun. But its smaller size should have allowed the planet to cool down to equilibrium about two billion years ago. The current surplus heat now appears to be generated by separation of hydrogen and helium deep within the planet. The heavier helium forms into raindrops and sinks through the hydrogen, generating heat as the helium settles toward the center of the planet. That separation does not happen at Jupiter because the planet has not cooled enough from gravitational collapse for the separation to begin.

*A. Various features in Saturn's cloudtops are apparent in this enhanced color image of the planet's northern hemisphere: a longitudinal wave is visible in the light blue region; small-scale convective cloud features (similar to, but much larger than, thunderstorms in Earth's atmosphere) appear in the brown belt; and an isolated convective cloud with a dark ring can be seen in the light brown zone. Voyager 1 took this photograph on*

*The late Observ. of Saturne.*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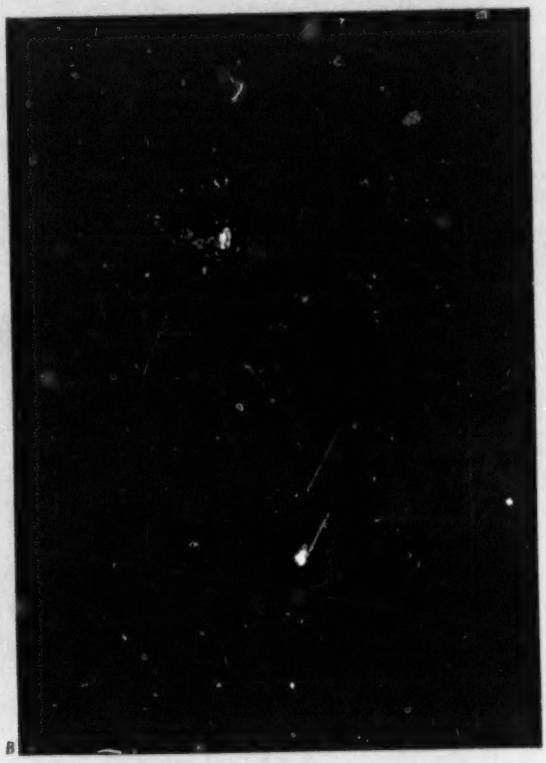
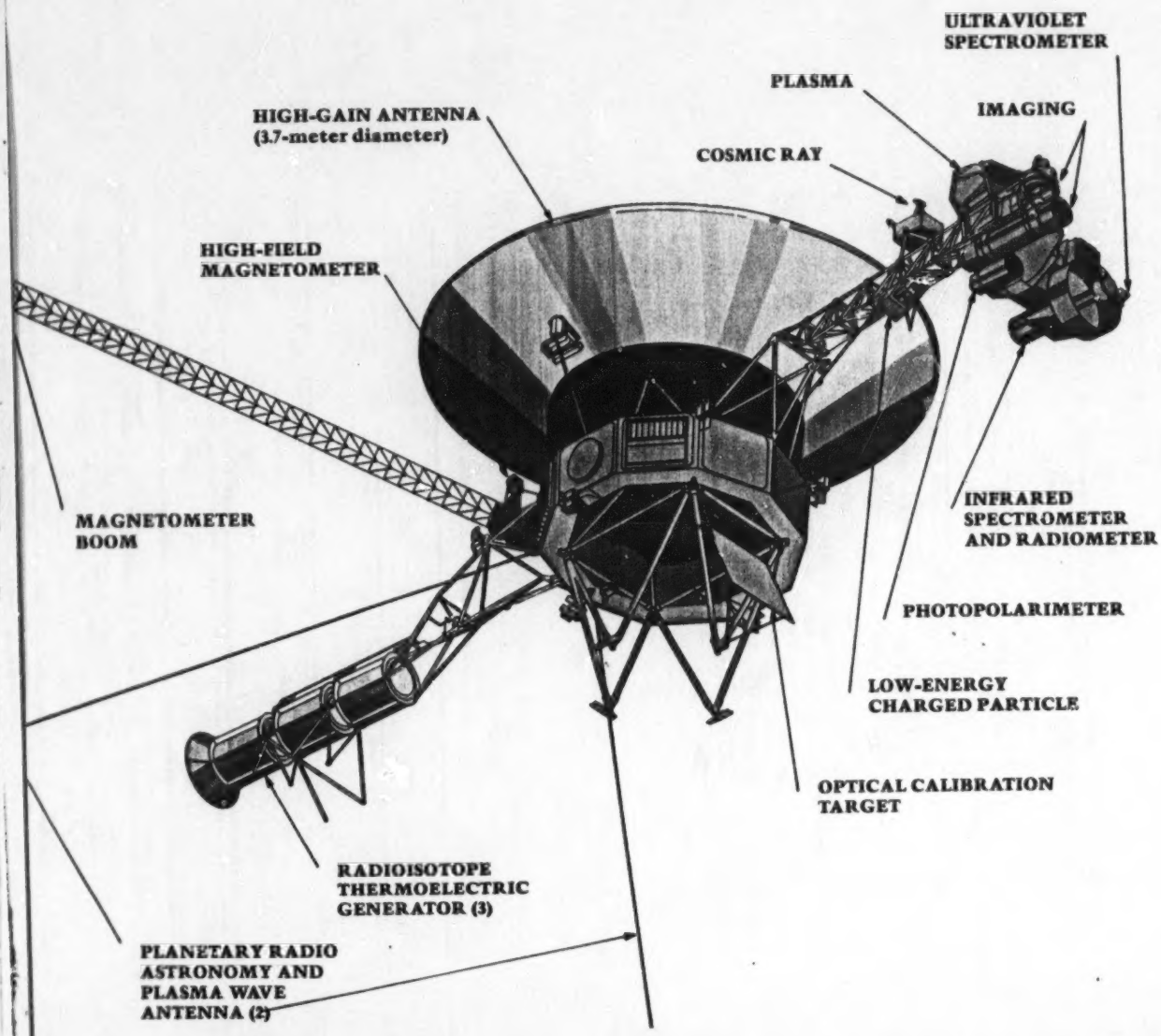

B

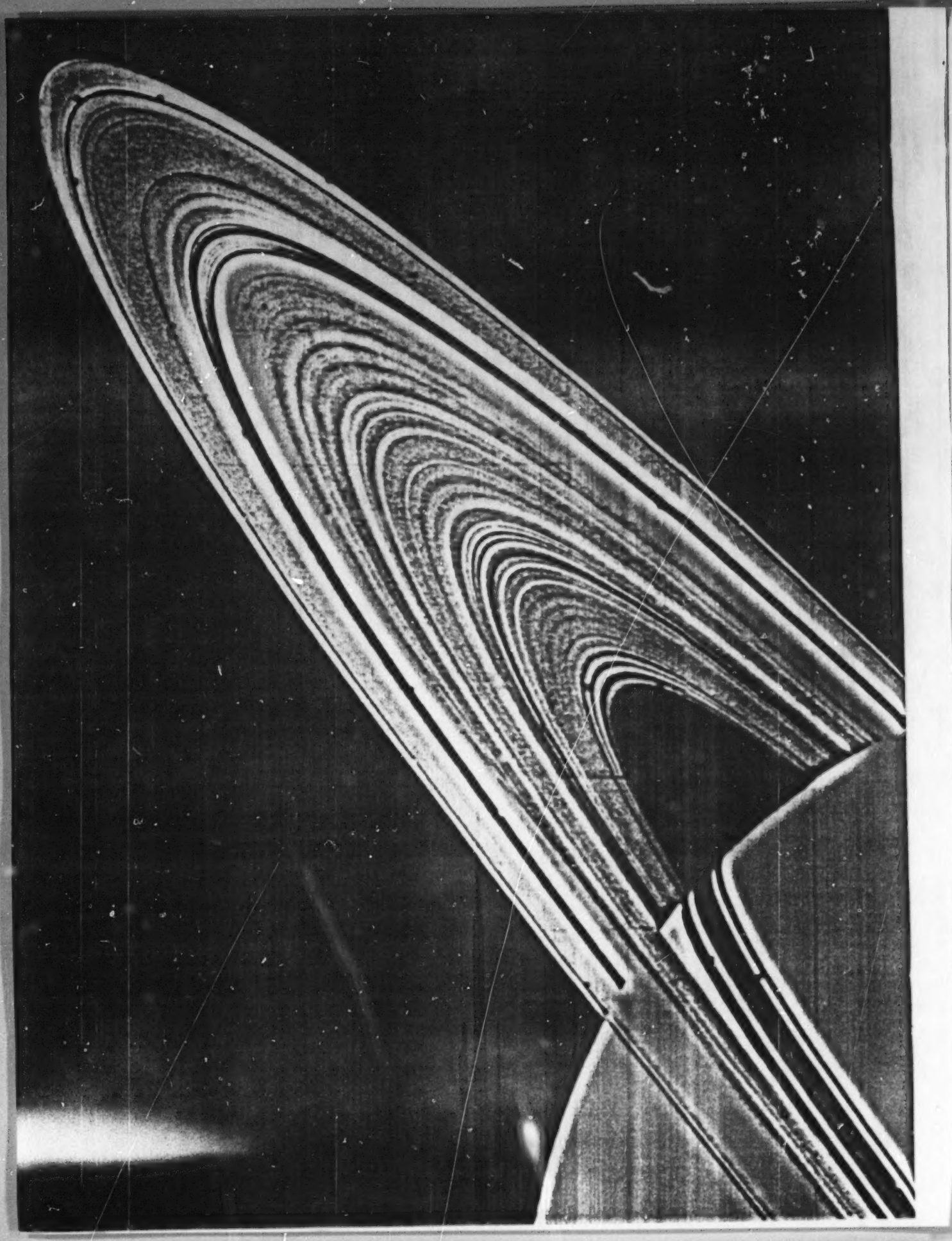
*November 5, 1980, from 9 million kilometers above the planet.*

*B. The prominent red oval in Saturn's south polar latitudes is visible in this photograph taken by Voyager 1 on November 12, 1980, at a distance of 5 million kilometers from the planet. The red cloud feature (lower left), approximately 3,000 kilometers long, was first seen by Voyager imaging-team scientists in August 1980. The feature resembles Jupiter's much larger Great Red Spot.*

**VOYAGER SPACECRAFT FEATURES**

| | |
|---|---|
| Spacecraft Mass | 825 kg (1,819 lb) |
| Science Instruments Mass | 105 kg (232 lb) |
| High-Gain Antenna Diameter | 3.7 m (12 ft) |
| Radioisotope Thermoelectric Generator (RTG) Power (at Saturn) | ~430 W |
| Data Storage Capability | 538 million bits |
| X-Band Data Rate<br>at Jupiter<br>at Saturn | <br>115,200 bits per second<br>44,800 bits per second |





## The Rings

Classic astronomy proclaimed three—possibly four—rings around Saturn: the A-ring, B-ring, and C-ring. (The fourth ring, a subject of considerable scientific debate, was the D-ring.)

In addition, Pioneer 11 found a narrow F-ring just outside the bright A-ring, and ground-based astronomers detected a wide, faint E-ring—the outermost known ring—beyond the F-ring.

Voyager 1 also confirmed a G-ring that orbits the planet about 110,000 kilometers from the tops of the clouds—only 2,600 kilometers inside the point where Voyager 2 should slice across the ring plane while the spacecraft is behind the planet and out of sight of Earth.

Imagine the surprise of Voyager scientists when they saw signs in early spacecraft photos that the classic rings appeared to be arranged into separate ringlets! The closer Voyager 1 came to the rings, the more ringlets could be seen—until there appeared to be several hundred. In the Cassini Division—a large gap between the B- and A-rings that appears clear and empty from Earth—Voyager scientists discovered at least five clearly defined ringlets.

Their surprise would not stop there: a picture of the F-ring showed what appeared to be three separate, braided strands. After almost nine months of study, scientists are still without a clear explanation of the phenomenon. Voyager 2 will take a special series of pictures of the F-ring to help solve the puzzle.

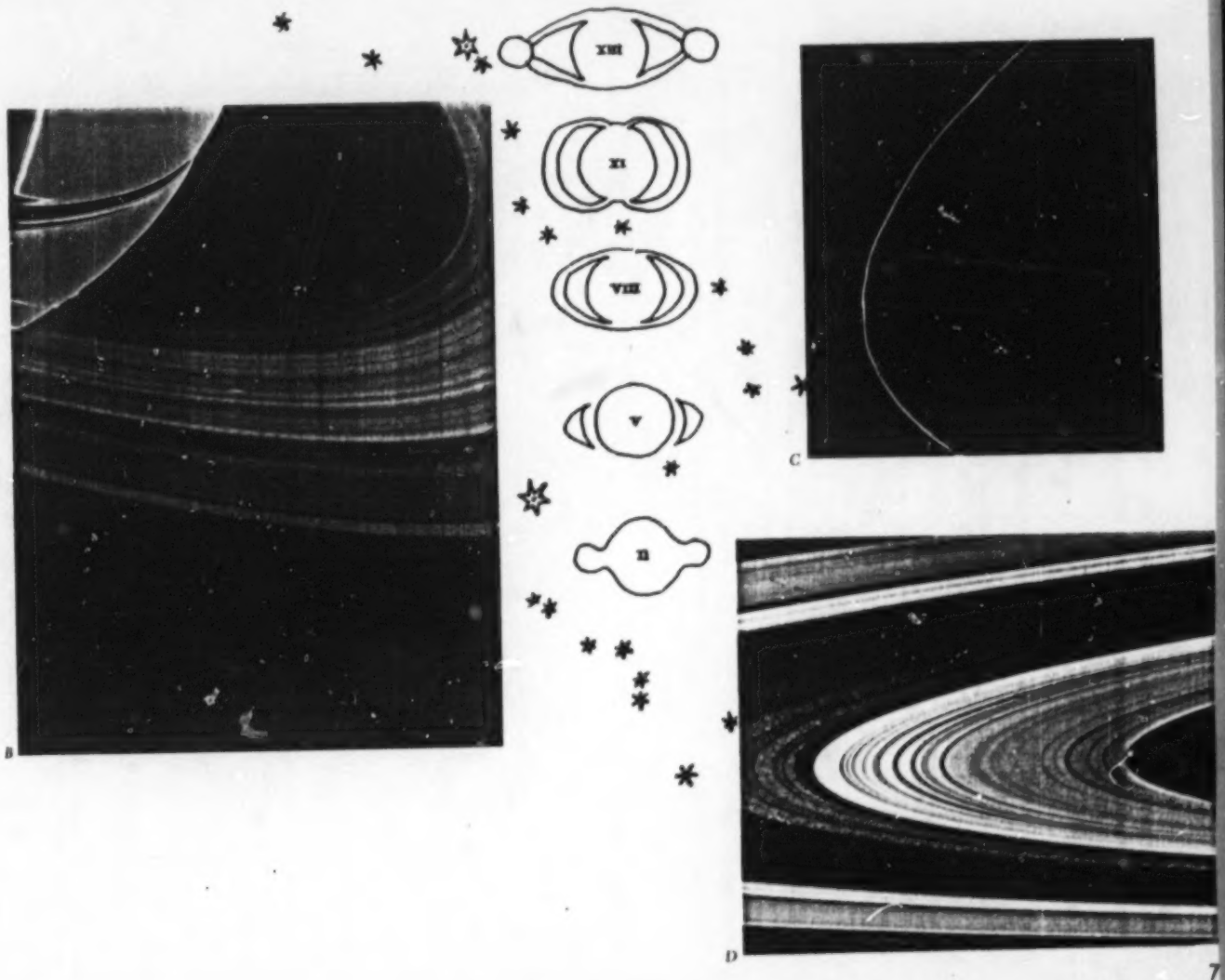
Scientists long ago determined that the rings are not solid disks, but are composed of billions of particles. The particles range in size from dust motes to tens of meters across. Average

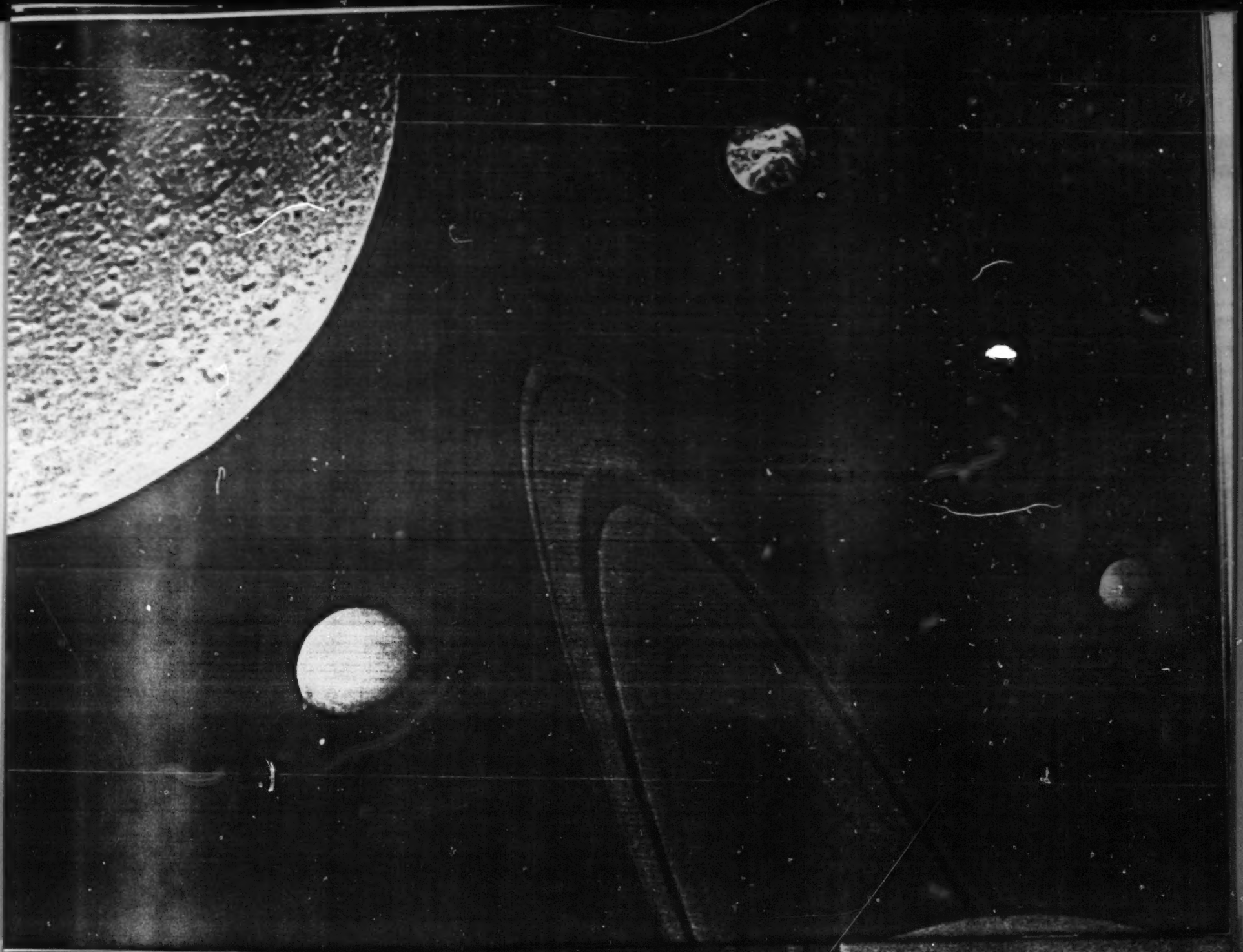
*A. This two-image mosaic of Saturn's extraordinarily complex rings, taken by Voyager 1 on November 6, 1980, at a range of 8.6 million kilometers, shows at least 95 individual concentric features in the rings.*

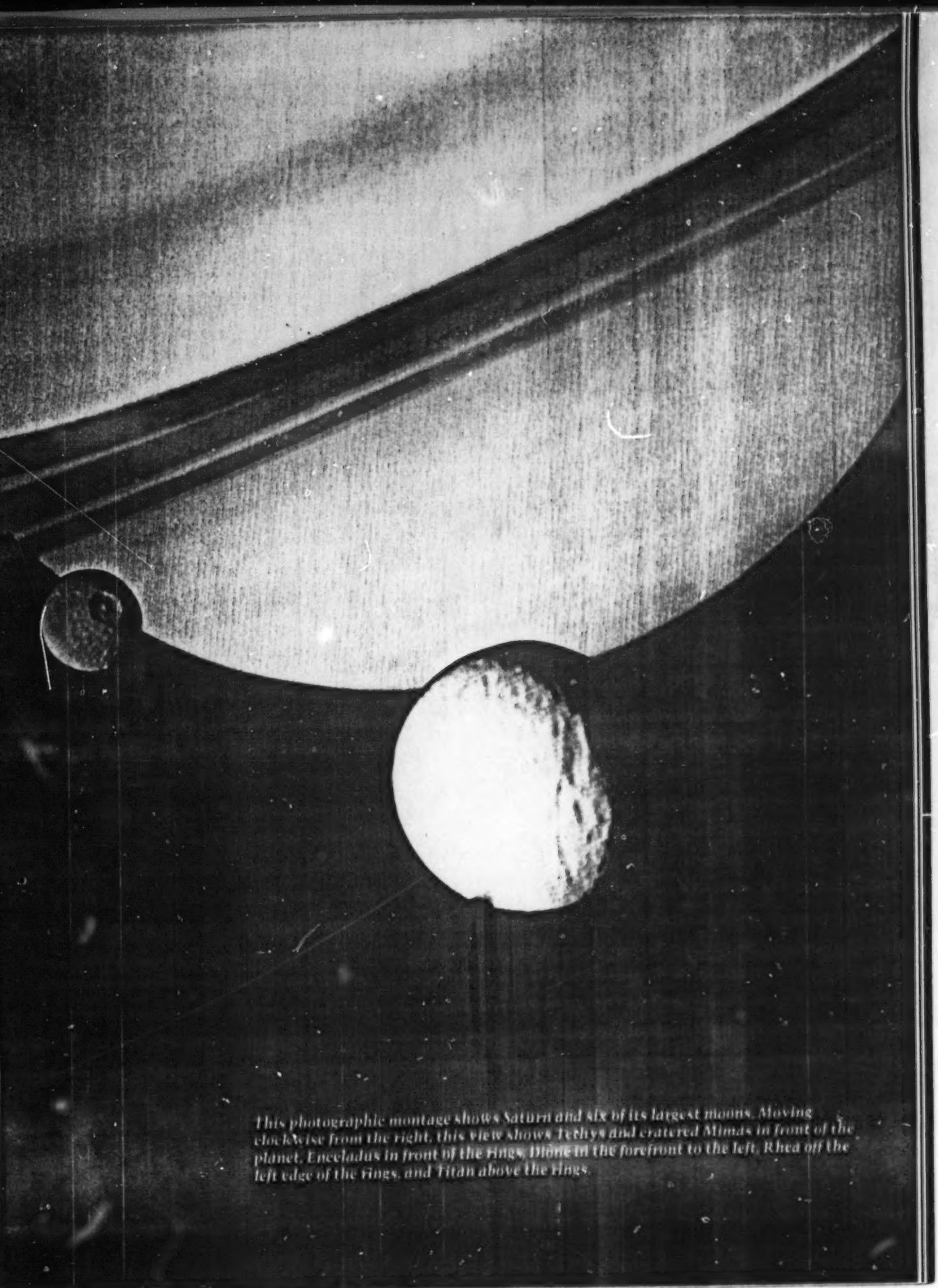
*B. Saturn and its rings were photographed by Voyager 1 on November 13, 1980, at a distance of 1.5 million kilometers, as the spacecraft began to leave the Saturnian system. The dark band cutting through the crescent is the shadow of the rings.*

*C. Saturn's narrow F-ring appears to be composed of three separate strands that are twisted and kinked. Voyager 1 took this photograph on November 12, 1980, when the spacecraft was 951,000 kilometers from the ring.*

*D. Voyager 1 photographed the underside of Saturn's rings on November 12, 1980, from 717,000 kilometers away.*







*This photographic montage shows Saturn and six of its largest moons. Moving clockwise from the right, this view shows Tethys and cratered Mimas in front of the planet, Enceladus in front of the rings, Dione in the forefront to the left, Rhea off the left edge of the rings, and Titan above the rings.*

particle size varies from ring to ring.

Ground-based observers have found that the ring particles are covered almost entirely with ice. The ring particles appear to be a source of giant electrical discharges that were detected by the radio-astronomy instrument on Voyager 1.

One of the most important scientific observations by Voyager 2 will begin about four and one-half hours before closest approach to Saturn. The planet and the rings will pass between a star called Delta Scorpii and the spacecraft. The photopolarimeter will measure the brightness of the star as it passes behind the rings. Scientists will be able to count the rings since the starlight will wink on and off as the star passes behind ringlets and relatively clear regions. Particle sizes in the rings, within certain ranges, will also be measured.

## The Satellites

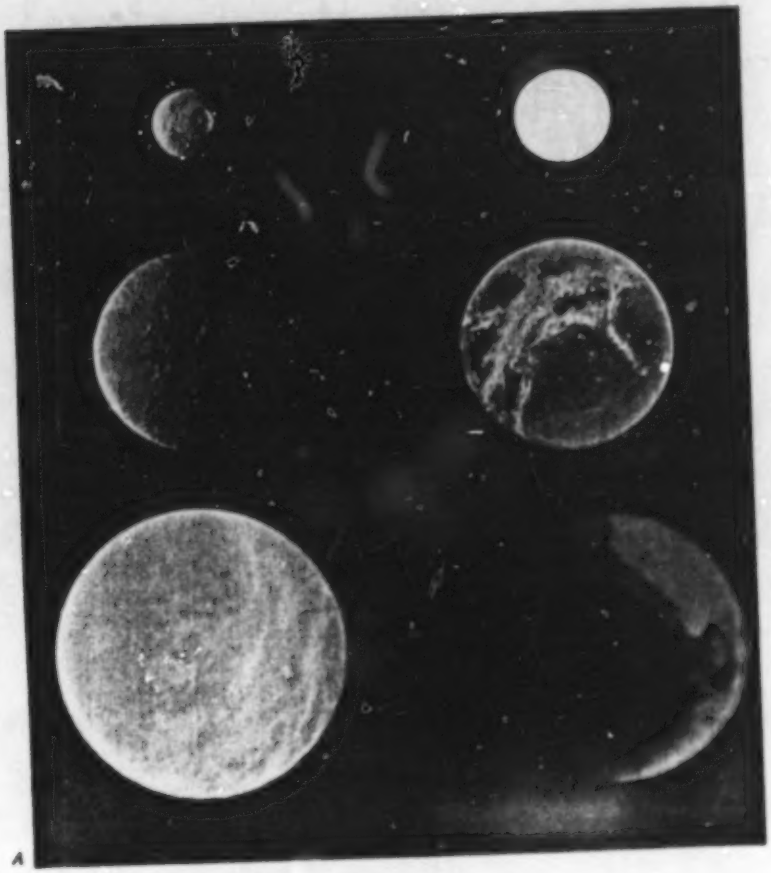
Voyager scientists and ground-based astronomers have recently discovered six satellites orbiting Saturn, increasing the known total to 17. Three new satellites were found in Voyager 1 photographs, while three were detected in 1980 by telescopic observation. Others may exist, still undiscovered, and Voyager 2 will search for them.

One satellite was found, in a Voyager 1 photograph, near the outer edge of the A-ring; scientists believe it defines that ring's boundary. Two others, found in Voyager 1 pictures, bracket the narrow F-ring, probably holding its particles, by gravitational attraction, within the ring's narrow boundaries. Another pair, discovered from Earth in 1966 and 1977, move in nearly identical orbits, trading places each time they draw close together.

Three more newly discovered satellites are associated with two that were already known; one shares Dione's orbit while the other two circle Saturn with Tethys.

Voyager 1 concentrated on large Titan, but also photographed and studied every satellite it came close to. Photographs of Titan did not show the surface, but they did reveal other phenomena, such as a detached haze layer high above the atmosphere. Other instruments made important measurements of Titan's atmospheric composition—mostly nitrogen and methane—and the satellite's diameter and surface pressure. Voyager 2 will pass farther from Titan than Voyager 1 did, but will nevertheless make complementary observations.

Voyager 2 will approach five Saturnian satellites closer than Voyager 1 did, providing higher-resolution photo-



A

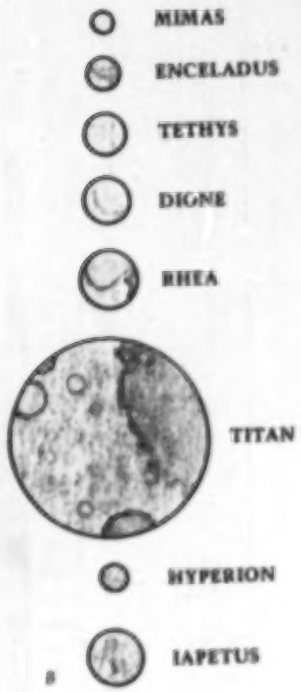
graphs of them. They are Iapetus, Hyperion, Enceladus, Tethys, and Phoebe. (Voyager 1 passed so far from Phoebe—13.5 million kilometers—that no attempt was made to photograph it.) Voyager 2 will also attempt to photograph the six small satellites discovered by Voyager 1 and by ground-based observers.

*will attempt to photograph all 17 known satellites.*

*C. Dione's surface shows many impact craters—the result of collisions with cosmic debris. The largest crater is less than 100 kilometers in diameter. The images in this mosaic were taken on November 12, 1980, when Voyager 1 was 162,000 kilometers from Dione.*

*A. Saturn's six large, icy satellites are shown to scale: Mimas and Enceladus (top), Tethys and Dione (middle), and Rhea and Iapetus (bottom). The satellites' color and brightness have been preserved for comparison.*

*B. Until November 1980, Saturn's satellites had remained faceless because of their vast distances from Earth. Voyager 1 photographed eight of Saturn's moons, illustrated here in their relative sizes, revealing many fascinating features. Voyager 2*



## Titan

While Titan, Saturn's largest satellite, was an important Voyager 1 target, Voyager 2 will have only a distant encounter with this planet-sized moon, and will instead concentrate on the rings and the other satellites.

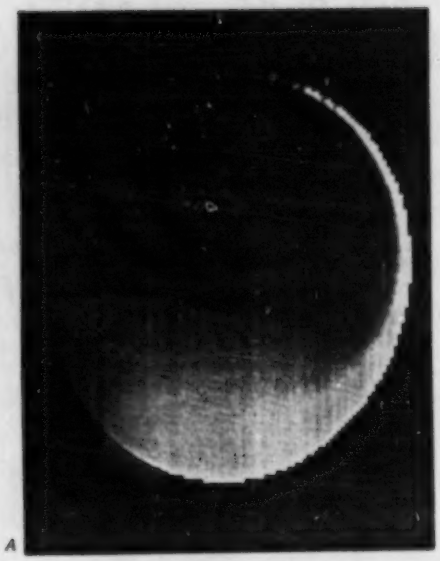
Studies of Titan by Voyager 1 yielded a surprising result—Titan is not the largest satellite in the solar system, as had been believed. Instead, it gives way to Jupiter's Ganymede. Measurements of Titan from Earth and Pioneer 11 included Titan's clouds. But Voyager 1 found those opaque clouds are 240 kilometers above the surface.

Some of the most interesting results came from studies of Titan's atmosphere. The methane that was first seen in 1948 was present in abundance. The long-suspected "invisible

*A. Titan is the only moon known to have a dense atmosphere. This contrast-enhanced photograph, taken by Voyager 1 on November 12, 1980, at a distance of 190,000 kilometers, shows details in the haze that covers Titan. At the time of this photograph, the seasons on Titan were equivalent to early April on Earth—that is, spring in the darker northern hemisphere and fall in the lighter southern hemisphere. A season on Titan lasts about seven years. The jagged edge is an artifact of computer processing.*

*B. Layers of haze covering Titan are visible in this false-color photograph taken by Voyager 1 on November 12, 1980, at a distance of 4,000 kilometers.*

*C. Titan is larger than the planet Mercury. This color-enhanced photograph was taken on November 12, 1980, when Voyager 1 was 236,000 kilometers from the satellite. Computer processing has exaggerated the haze layers, producing the white fringe surrounding Titan.*



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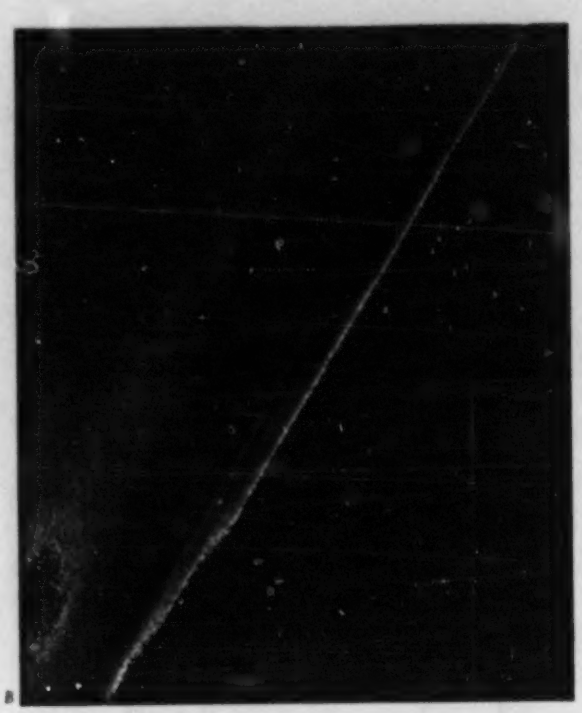

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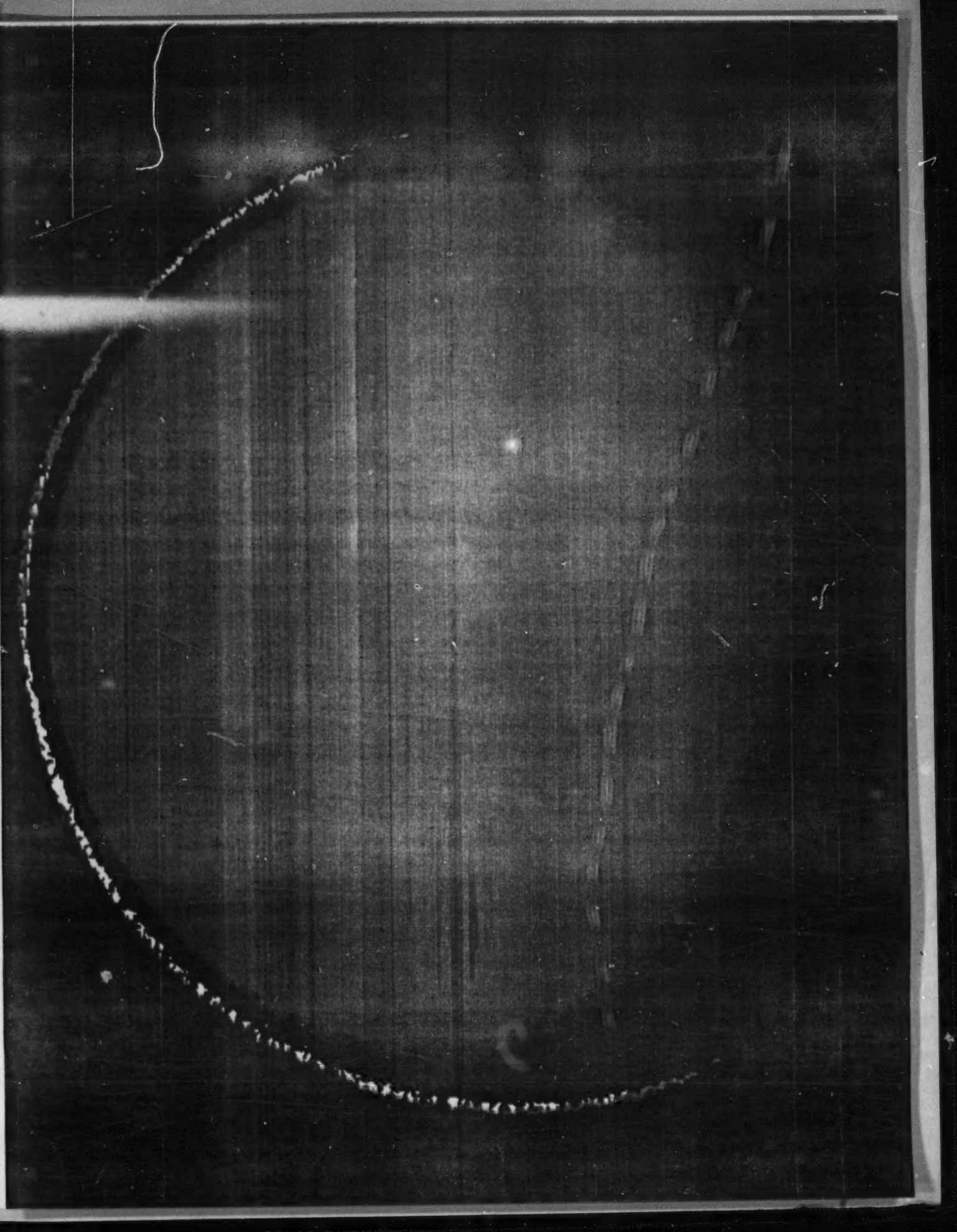


gas" turned out to be nitrogen, which comprises about 80 percent of the total atmosphere. Titan's atmospheric pressure near the surface is 60 percent greater than Earth's pressure at sea level.

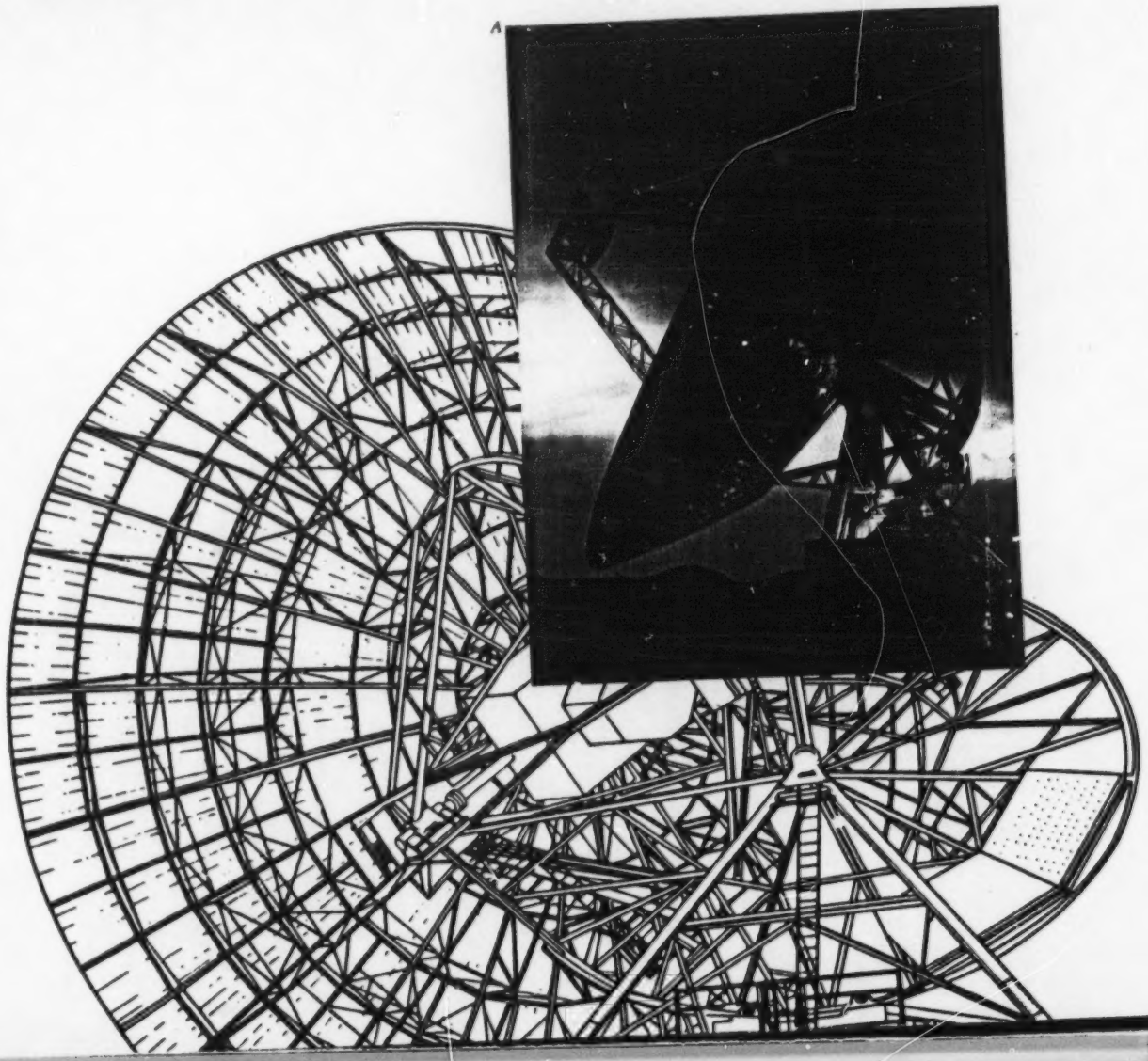
Titan's surface, hidden by a dense, optically thick haze, cannot be seen in photographs from Voyager 1. But other measurements indicate methane could possibly play the same role on Titan as water does on Earth—present as rain, snow, ice, and vapor. Clouds may drop liquid-methane rain on the surface. Rivers of methane may cut through glaciers of methane under a nitrogen sky. Titan's methane, through continuing organic chemistry, is converted to ethane, acetylene, ethylene, and hydrogen cyanide. The hydrogen cyanide is especially important because it is a building block of amino acids. Titan's low temperature, however, undoubtedly inhibits very complex organic chemistry.

## The Magnetosphere

Barely two years have passed since Pioneer 11 determined for the first time that Saturn has a magnetic field; scientists thought it did, but they did not have measurements of such a field. Saturn's field, like those of Earth and Jupiter, is roughly similar to that of a bar magnet. Saturn's magnetosphere differs in strength and in the fact that the axis of the bar magnet at Saturn is nearly the same as its rotational axis; Earth's and Jupiter's magnetic fields are offset substantially.

Voyager 1 also determined with high precision the length of a day on Saturn: 10 hours, 39 minutes, 26 seconds. That rotation period refers to the interior of Saturn and was measured with radio-astronomy data obtained since January 1980. Earth-based measurements, which are of the clouds, showed similar periods in temperate and polar regions, but a much shorter period (10 hours, 14 minutes) near the equator, indicating the presence of a high-velocity equatorial jet stream that was verified by Voyager 1.

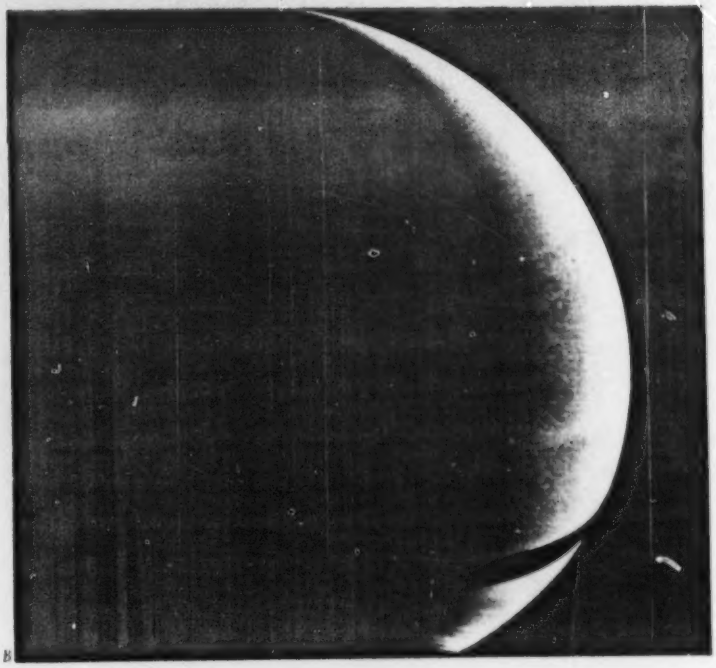
Voyager 2 has added a footnote about Jupiter's magnetic field. Scientists studying plasma-wave data from Voyager 2 have found evidence that Jupiter's magnetotail extends at least 500 million kilometers beyond Jupiter, and may extend beyond Saturn's orbit. That is evidence of the extent to which Jupiter's magnetic field trails away from the side of the planet opposite the Sun. The plasma-wave team suspects that Saturn and Voyager 2 might be immersed in Jupiter's magnetotail several times during the encoun-



ter period. If that is the case, they say, the magnetic field measurements Voyager 2 makes at Saturn should be vastly different from those made by Voyager 1.

*A. The giant 64-meter antennas of the worldwide Deep Space Network receive Voyagers' radio signals and route them to Mission Operations at JPL for analysis.*

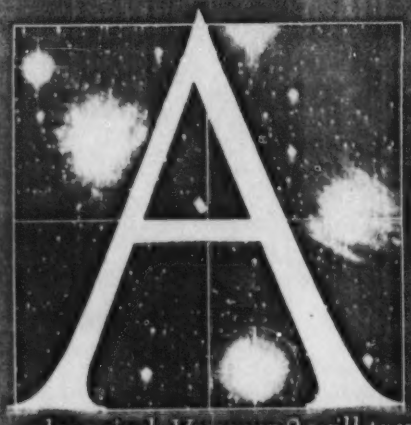
*B. The crescent of Saturn was photographed through ultraviolet, violet, and green filters on December 1, 1980, when Voyager 1 was 24.8 million kilometers beyond the planet.*



B

## VOYAGER SCIENTIFIC INVESTIGATIONS

| Experiment | Principal Investigator | Primary Measurements |
|---|---|---|
| Cosmic Ray | R.E. Vogt, California Institute of Technology | Energy spectra and isotopic composition of cosmic ray particles and energetic particles in outer planetary magnetospheres. |
| Imaging Science | Team Leader, Bradford Smith, University of Arizona, Tucson | Imaging of planets and satellites at resolutions and phase angles not possible from Earth. Atmospheric dynamics and surface structures. |
| Infrared Interferometer Spectrometer | Rudolf Hanel, Goddard Space Flight Center | Energy balance of planets. Atmospheric composition and temperature fields. Composition and physical characteristics of satellite surfaces and Saturn's rings. |
| Low-Energy Charged Particles | S. M. Krimigis, Johns Hopkins University, Applied Physics Laboratory | Energy spectra and isotopic composition of low-energy charged particles in planetary magnetospheres and interplanetary space. |
| Magnetometer | Norman Ness, Goddard Space Flight Center | Planetary and interplanetary magnetic fields. |
| Photopolarimeter | Arthur L. Lane, Jet Propulsion Laboratory | Methane, ammonia, molecular hydrogen, and aerosols in atmospheres. Composition and physical characteristics of satellite surfaces and Saturn's rings. |
| Planetary Radio Astronomy Plasma | James Warwick, Radiophysics, Inc. | Planetary radio emissions and plasma resonances in planetary magnetospheres. |
| Plasma Wave | Herbert Bridge, Massachusetts Institute of Technology | Energy spectra of solar-wind electrons and ions, low-energy charged particles in planetary environments, and ionized interstellar hydrogen. |
| Radio Science | Frederick L. Scarf, TRW Systems Group | Dynamics of planetary magnetospheres and satellite perturbation phenomena associated with charged particle-plasma wave interactions. Determination of electron density. |
| Ultraviolet Spectrometer | Team Leader, G. Len Tyler, Stanford University | Physical properties of atmospheres and ionospheres. Planet and satellite masses, densities, and gravity fields. Structure of Saturn's rings. |
| | A. Lyle Broadfoot, University of Southern California | Atmospheric composition including hydrogen to helium ratio. Thermal structure of upper atmospheres. Hydrogen and helium in interplanetary and interstellar space. |



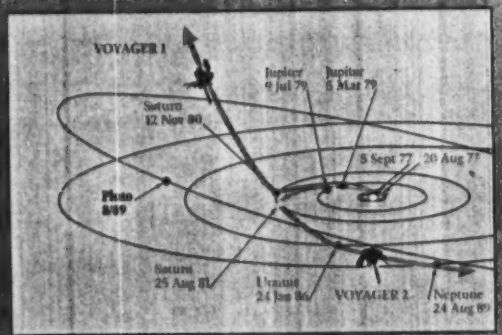
As Voyager 1 passed Saturn, the planet's gravity boosted the spacecraft up out of the ecliptic plane. The spacecraft is now outward bound on a journey with no return—into galactic space. As long as the spacecraft can be tracked, engineers will listen to Voyager 1's radio signals in an effort to determine just where the solar wind ends and evidence of a stellar wind begins.

Meanwhile, Voyager 2 flies a path to Saturn that will send it toward distant Uranus. Since both Voyagers appear to be capable of years of operation, NASA made the decision to continue their missions. As Voyager 1 searches for the boundary of the solar wind, Voyager 2 will travel on to Uranus. Approximately four years after leaving Saturn, Voyager 2 will arrive at Uranus—in January 1986—providing the first clear, close-up photographs of that distant planet.

Uranus is markedly different from Jupiter and Saturn. It is tilted almost 90 degrees on its axis, rolling along its path around the Sun like some huge celestial barrel. In contrast to the other planets, Uranus first points its north pole sunward, then 42 years later, its south pole. In 1986, the orientation of Uranus—as it moves on its side with one pole pointed sunward—will allow Voyager 2 to fly past the equator and both poles as well. Voyager 2 will study any magnetosphere and plasma that may be present and could photograph the sunlit hemisphere of Uranus, all of its satellites, and the rings that were discovered in 1977.

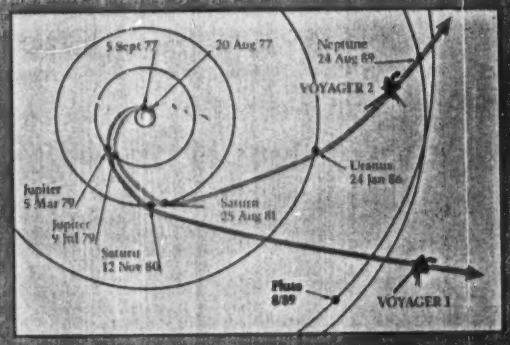
Voyager 2 will continue toward Neptune, and may make close observations of that distant planet in August 1989.

At last, one day far in the future, having completed their part in the studies of the heavens that began in earnest with Galileo Galilei and his first tiny telescope, the Voyagers will near the end of their mission. Their attitude-control gas spent, their energy depleted, they will no longer respond to commands. The two spacecraft will drift forever, through the Milky Way galaxy, their mission of exploration completed.




A. Since its flyby of the Saturnian system in November 1980, Voyager 1 has been on a trajectory that is taking the spacecraft out of the solar system. Voyager 2 will reach Saturn in August 1981 and will continue on to Uranus and possibly to Neptune.

B. The Voyager 1 and 2 trajectories are shown here in a heliocentric (Sun-centered) view.




C. This computer-simulated drawing depicts Voyager 2 as it flies past Uranus in 1986. The background accurately shows star locations.